# INTERDISCIPLINARY STUDY OF GULF STREAM WARM CORE RING PHYSICS CHEMISTRY, AND BIOLOGY

Report of the Warm Core Rings Data Workshop
July 6-19, 1983
Whispering Pines Conference Center
W. Alton Jones Campus, University of Rhode Island
West Greenwich, Rhode Island

Edited by Peter H. Wiebe

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# REPORT OF THE WARM CORE RINGS DATA WORKSHOP

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# I. Introduction

## A. Objectives/Purpose of the Workshop

The warm-core rings program held an intensive 2-week data processing and analysis workshop during the period 6 to 19 July 1983 at the Alton Jones Campus Conference Center of the University of Rhode Island. The purpose of the workshop was to bring together all of the program's principle investigators, their graduate students and technical associates, and scientific collaborators in order to jointly discuss and analyze the multifaceted data sets collected on the five multi-ship cruises to Gulf Stream warm-core rings (see Warm-Core Rings Executive Committee, 1982 and Joyce and Wiebe, 1983 in Section V of this report for overviews of the field program). The workshop was structured to permit individuals and working groups maximum flexibility in organizing their work schedules (see section two, overall workshop organization plan). Lectures of 30 to 60 minutes were held in the morning and afternoon to permit investigators to summarize their findings and to foster the exchange of data and ideas about the structure, dynamics and evolution of warm-core rings. Morning lectures focused on the surface and seasonal thermocline waters of the ring core; afternoon lectures focused on the thermostad and deeper ring water masses as well as flow fields generated by interactions with the Gulf Stream and continental shelf and Slope Water. A list of lecturers and lecture titles is given in section two.

A number of working groups were formed to tackle data processing or intercomparison problems, to foster data synthesis in areas of concern to a number of investigators, and to work on scientific questions that arose during the workshop. A list of working groups, their purpose, and a summary of their findings are given in section three.

In order to facilitate the exchange of data and their interpretation, investigators were encouraged to bring their micro-computers, disc drives, printers, etc. for real-time data analysis and word-processing. One of the three main conference rooms was used exclusively for this activity. Additionally, terminals with modems were used to acesss data located on the main frame VAX computers at Woods Hole, University of Rhode Island, and University of Miami.

The Warm-Core Rings Executive Committee gratefully acknowledges the skillful coordination of the Workshop and logistical support arranged by Alfred Morton and Mary Jane Lyons. Thanks also to Mary Jane for the long hours spent typing and proofing this Workshop report.

B. Some Important Findings from the Workshop

1. Origin of Waters in Warm-Core Ring 82-B

Remote sensing imagery from February 1982 indicated that 82-B formed with a surface temperature of 19-20°C. When first observed by RV/OCEANUS in March, an isothermal, isohaline core with a temperature of 17.7°C and a salinity of 36.5°/oo extended from the surface to 300 m depth. When sampled on our first WCR cruise in April, the thermostad layer was nearly 450 m thick, and the core temperature and salinity had been lowered to 15.7°C and 36.24°/oo, respectively. One-dimensional mixed layer models incorporating convective cooling, evaporation, and entrainment of deeper water would not "balance" without the addition of a small amount (a layer 20 m thick) of Slope Water. Thus, the core water for the start of the time series cruises appears to be predominantly vertically modified Sargasso Sea water.

Zooplankton species composition in stratified hauls revealed that waters below 500 to 600 meters in the warm-core ring 82-B were very similar to water at similar depths in the Slope Water and contrasted sharply with species abundances and presence in the Gulf Stream or Sargasso Sea. This pattern was evident in species counted to date of copepods, chaetognaths, and euphausiids from the first sampling of 82-B approximately 3 weeks after formation and at subsequent sampling periods. These findings give rise to the hypothesis that the waters of ring 82-B were predominately Gulf Stream and Sargasso Sea above 500 to 600 meters and predominately Slope Water at greater depths. However, Slope Water and continental shelf species of zooplankton were rare but present in the surface and thermostad waters forming the core of 82-B at age 3-weeks, suggesting that transport of water and biota from outside the ring into the core waters took place shortly after the ring was formed. There was a substantial abundance of these species by April.

A deep secondary particle maximum at temperatures between 5 and 10°c on the flanks of the newly formed 82-H was found between the same temperature intervals in the Gulf Stream off Cape Hatteras and the speculation is that this deep layer found in both 82-H and 82-B is not generated locally, though it may be influenced by contact with continental slope sediments. If true, then water as cold as 5°C may have been involved in the formation of 82-B. It seems clear, however, that the initial waters of the thermocline and above (>10°C) in 82-B were of Gulf Stream and Sargasso sea origin, although slightly modified by Slope Water "contamination". Below this, the zooplankton and particle concentrations give apparently conflicting evidence on the origin of 82-B water. This can be resolved if the deeper particle-laden Gulf Stream water has a strong component of Slope Water entrained near Cape Hatteras.

2. Transformations of 82-B During the Time Series

One of the most notable transformations of 82-B was the modification of the core waters by atmospheric exchange and, to a lesser degree, mixing with the Slope Water as described above. Further analysis of mixed layer models suggests that long term changes are roughly consistent with atmospheric interactions. Clearly these models need to be revised to include aspects of the horizontal exchange in order to properly model the rates at which the core is modified.

The integrated chlorophyll shows slight decreases from April/May to June with the surface waters (0-100 m) being considerably lower than the Slope Water. However, in April, the ring thermostad extended to over 400 m and significant chlorophyll concentrations (>1 mg/m$^3$) were found to 200+ meters while silicon uptake was occurring to at least 300 m. Thus, although the mixed layer was 3 or 4 times deeper than the photic zone, and the surface water concentrations of plants were relatively low, integrated levels of plant biomass and production were as high or higher than adjacent waters. Theoretical modelling studies indicated that if rapid mixing is occurring even to depths in excess of 300 m, phytoplankton cells would experience average light levels above that existing at the 1% level which in April occurred about 75 meters; deep mixing could perhaps account for the high integrated biomass.

Excesses of radon were found in waters making up the entrainment fields on the periphery of ring 82-B during most sampling periods and with increasing frequency in the surface waters, thermostad, and deeper portions of the ring from April to June to August. Radon excesses over the equilibrium values expected from the natural decay of radium could only come from waters recently (days to a week or two) in contact with continental shelf and slope sediments and indicated repeated and rapid exchange of ring and adjacent water.

Evolution of ecosystem structure in the case of 82-B gave rise to a hybrid structure in which both opportunistic warm-water and cold-water floral and faunal elements were favored. The structure of the plankton community in the top 100 m of 82-B changed from predominantly plant biomass in April toward a condition characterized by increasing heterotrophic biomass and activity in June. During the June cruise, there was a strong biomass maximum localized at ring center in which levels of chlorophyll, ATP non-living POC and bacterial growth rates were as high or higher than observed elsewhere in or near the ring. This pattern is similar to the spring-summer development in shelf water. This conclusion amplifies other observations concerning the oceanic-coastal hybrid character of rings which evolve thru the summer (e.g. 81-D). A number of chaetognath, copepod, and euphausiid species normally found only in Slope Water, were present at ring center within 3-weeks of ring formation. Numbers of some of these species were especially high in June (e.g. *Sagitta tasmanica*, *Euphausia krohnii*, *Thysanoessa gregaria*, *Pleuromamma borealis*, *Centrogages typicus*). Most warm-water species survived throughout the ring's lifetime.

Trace metal data for 82-B appear to lie on a mixing curve between Slope Water and Sargasso Sea water characteristics. It seems likely that entrainment events are responsible for this mixing.

The motion of ring 82-B and its decay were fairly variable. There is an apparent relationship between the motion and topography with the ring speeding up as it passes the outfalls from submarine canyons. In general, the ring did not move significantly up the slope. Decay of the potential and kinetic energy occured with an e-folding time of approximately 120 days during April to June and then much more rapidly (time scale of about 12 days) after June.

Analyses of the CZCS data strongly suggest that the spring surface bloom of phytoplankton occurred simultaneously over the shelf and Slope Water and persisted only for a very short period of time. However, the core of ring 82-B stood out dramatically because the surface concentrations appeared to peak at a later time. Modelling studies suggest this behavior is quite consistent with a later stratification of the ring core because the atmosphere becomes warmer than the surface waters significantly later due to the higher core surface temperatures.

3. Temporal and Spatial Variability Within Warm Core Rings.

Physical, chemical, and biological characteristics of rings change more rapidly and on shorter space scales than was orginally expected when this research was planned. A wide range of time scales for property variations were examined including changes within an hour to a day at specific stations, changes within days to two weeks at repeated sampling of the ring core, and changes over periods of months during the time-series cruises from March to October. Rather than a gradual evolution of ring characteristics from its Sargasso Sea origin toward Slope Water conditions, changes occurred over short intervals of time caused by specific events. The Gulf Stream played a major role in these events as did shelf water and Slope Water entrainment fields.

One entrainment event was studied in detail during the June 1982 measurements. The OCEANUS and ENDEAVOR performed tow-yo sampling of biological and physical properties in the upper 100 to 300 m. Transport of nearly pure shelf water produced a streamer along the eastern side of the ring; it amounted to 0.1-0.15 Sverdrups, although nearly 1 SV transport was observed for water in the upper 100 m with temperatures $<12^{o}c$. The forces responsible for streamer formation and their pattern of behavior have not yet been described from first principles. These streamers can account for the lowering of surface salinities with time in the ring, and they can provide an input of silica and shelf/Slope Water organisms to the upper 50 m of the ring.

During the June multi-ship experiment in the center of 82-B, a 4-km-wide intense current jet was observed by the acoustic doppler current profiler near the center of the ring on two radial sections made by the ENDEAVOR. The current jet was isolated in the upper 50 meters with an 80 cm/sec difference in currents relative to the waters on either side and below. No clear water mass signature is available which would permit an unambiguous origin from the shelf/Slope Water via a streamer. The current jet was swirling about the ring in the direction of ring core currents, but there was evidence for large, local departures from solid body rotation in the ring core.

Short horizontal and vertical scales of variation exist in the high velocity region of the ring, resulting in complex structures in the frontal region between the ring and its surroundings. These features are very well resolved in the continuous in situ CTD-O2 data, tow-yo sampling, and remote sensing imagery. Sampling showed Benthosema glacialis, a small Slope Water fish with a limited range of mobility, was being concentrated between the eastern edge of the ring and an entrainment feature. In a collaborative effort, biological and physical investigators are examining the implications of these observations on the circulation and transport of water at the boundary of rings.

A large variety of properties yield information on the changes that occur at depth within a ring. Transects of suspended particles, organically bound copper, detrital organic carbon, and biogenic silica show mid-depth maxima that follow density surfaces beneath the thermostad waters. The measurements of excess radon at mid-depths in the ring also reflect relatively rapid injections of water at depths of several hundred meters that had been recently in the vicinity of the sea floor.

The concentrations of dissolved oxygen and nutrients in the thermostad and main thermocline waters changed in response to respiratory and organic decomposition processes during the interval from April to June to August. These changes were consistent with biological observations, though they are considerably more rapid than was expected based on previous estimates of these processes in oceanic water columns.

4. Rate Processes in Rings.

Numerous important findings regarding rates of viscous dissipation within the ring, rates of air sea interactions, and rates of biological activity have been documented for warm-core rings. In ring 81-D, turbulent energy dissipation was extremely low in the thermostad, but relatively high in the thermocline under the thermostad and at the edge of the ring. Estimates of vertical diffusivities of buoyancy calculated from turbulence levels were about 0.05 $cm^2/sec$ in the inactive thermostad and 0.1$cm^2/sec$ in the thermocline as measured by CAMEL during the fall cruise to ring 81-D. If all turbulence were generated by vertical ring current shear, the time scale for ring decay would be 3-4 years. From other studies, however, it would appear that much of the turbulence is generated by inertial waves trapped and focussed by the large lateral current shear of the ring boundary.

Intense evaporative cooling from February to April 1982 resulted in deep nitrate and phosphate being mixed to the surface of ring 82-B more rapidly than they could be utilized in the process of primary production. This resulted in unusual accumulations of these nutrients in near-surface waters, and set the stage for the phytoplankton bloom that developed in May. Prior to the bloom, the deep mixed layer of high nutrient content provided an opportunity to compare rates of nutrient uptake and remineralization in a mixed layer that was much deeper than the euphotic zone. Very high growth rates were observed for large centric diatoms. These rivaled the fastest rates that have been observed in laboratory culture studies, and lead to the inference that the net phytoplankton are an important food source for the herbivorous zooplankton in spite of their low abundance.

## II. Organization and Participation in the Workshop

### A. Participants

Warm Core Rings Executive Committee:

Dana R. Kester, Chairman
Peter H. Wiebe, Vice Chairman
Glenn Flierl
David R. Schink
James J. McCarthy
Terrence M. Joyce
Alfred W. Morton, Program Service Administrator
Mary Jane Lyons, Staff Assistant

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* -- Attended workshop summary sessions, July 18 & 19
** -- Attended NASA Ocean Color Working Group Meeting, July 8, 1983

B. Overall Structure

WARM-CORE RINGS DATA WORKSHOP
JULY 6-19, 1983
GENERAL FRAMEWORK

| DAY | 0900 | 1000-1600 | 1600-1700 |
|---|---|---|---|
| W 6 | GEN INTRO | VAX USAGE, TECHNIQUES, METHODS | OVERVIEW TALK |
| T 7 | OVERVIEW TALK | GROUP SESSIONS | OVERVIEW TALK |
| F 8 | | | |
| S 9 | RING | Individuals/groups work on | THERMOCLINE |
| S10 | CORE | data | |
| M11 | MIXED | | THERMOSTAD |
| T12 | LAYER | Informal talks - schedule to | |
| W13 | | be posted each day | ENTRAINMENT |
| T14 | | | |
| F15 | APPLICATION | | |
| S16 | OF MODELS TO | MODELLING DETAILS | |
| S17 | DATA SYNTHESIS | | |
| M18 | | SUMMARY TALKS (NSF/ONR/NASA REPS PRESENT) | |
| T19 | SUMMARY TALKS | END WORKSHOP | |

C. Daily Lectures -- Speakers and Titles w/Evening Sessions

| | | |
|---|---|---|
| Wed., July 6; | 0900 | P. Wiebe<br>Introduction/Logistics |
| | 1600 | R. Schmitt<br>History of 82-B: Evolution of surface, thermostad and thermocline structures |
| Thur., July 7; | 0900 | R. Smith<br>Time series of chlorophyll in Gulf Stream WCR 82-B and its environs |
| | 1600 | G. Flierl/W. Dewar/J. Wroblewski<br>Mixed layer physical-biological modelling |
| Fri., July 8; | 0900 | A. Hanson<br>Trace metal speciation in warm-core rings: Influence of and affect on biological processes occurring in WCR waters |
| | 1600 | D. Olson<br>The dynamic evolution of 82-B |
| Sat., July 9; | 0900 | G. Hitchcock/C. Langdon<br>Comparisons of primary particle distribution and productivity from C14 and oxygen measurements in warm-core rings |
| | | J. Bishop<br>Particle distribution and chemistry in warm-core rings as indicated by transmissometry, LVFS pump sample & sediment traps |
| Sun., July 10; | 1600 | K. Baker<br>Events affecting structure of 82-B |
| | | M. Roman<br>Formation of the DCM by differential zooplankton grazing |
| Mon., July 11; | 0900 | G. Fryxell/R. Gould<br>Gelatinous phytoplankton colonies in warm-core rings. Effect of storms? |
| | 1600 | P. Wiebe/J. Cheney<br>Source waters for the deeper portion of 82-B; Evidence from zooplankton distributions |
| Tues., July 12; | 0900 | M. Brown/D. Kester<br>Nutrient distribution in 82-B. What part of 82-B is a closed system? |

1600 J. Wroblewski/P. Franks
Part I. Offshore advection of fish larvae by WCR 81-G
Part II. Can models simulate observed biological fluxes in warm-core rings?

Wed., July 13; 0900 T. Smayda
Growth rates of net phytoplankton in Gulf Stream rings. Why aren't they more dominant?

1600 R. Lueck
Physical measurements of mixed layer, thermocline, and core fluxes in warm-core rings.

EVENING SESSION

7:00 p.m. Investigator discussions of program expectations and accomplishments

Thurs., July 14;0900 Tim Cowles
Zooplankton dynamics in 82-B -- more evidence for water mass structure in the deeper portion of 82-B

R. Backus/D. Olson
The possible concentrating of a Slope Water fish at the Eastern margin of 82-B by the June '82 entrainment feature

1600 T. Joyce/J. Bishop/P. Wiebe
The center of 82-B was not so dull after all or the June multiship studies

Fri., July 15; 0900 D. Nelson
Diatom growth and silicon cycling in ring 82-B

H. Ducklow
Bacterial abundance, biomass and production distributions, and dynamics in 82-B

1600 M. Kennelly
Velocity structure of 82-B

P. Blackwelder
Coccolithophore community structure in WCR 82-B; April, June & August

## EVENING SESSION

| | | |
|---|---|---|
| | 7:00 p.m. | Investigator discussions of program's future -- objectives, major questions, timing, etc. |
| Sat., July 16; | 0900 | S. Ikeda<br>Motion and structure of a warm-core ring |
| | | W. Dewar/G. Flierl<br>Transport and exchange rates in warm-core rings |
| | | D. Nof<br>Effects of the western boundary on anticyclonic eddies |
| Sun., July 17; | 0900 | J. McCarthy/M. Altabet<br>What happened to the 82-B nitrate? |
| | 1600 | D. Schink/J. Orr<br>Radon disequilibria in warm-core rings |
| Mon., July 18, | 0900 | T. Smayda<br>Analysis of observations and processes in ring 81-D |
| | | O. Brown<br>Evidence of ring 82-B evolution based on satellite imagery |
| | 1030 | Concluding sessions of working groups |
| | 1300 | Concluding sessions of working groups |
| | 1530 | T. Joyce/P. Wiebe (Discussion leaders)<br>Origin and time evolution of ring 82-B based on shipboard measurements |
| Tues., July 19; | 0900 | G. Flierl/J. McCarthy (Discussion leaders)<br>Scales of variability within ring 82-B |

## III. Summaries of Working Group Reports

### KNORR CTD BOTTLE DEPTH REPORT
Working Group Coordinator: T. Cowles

A working group was established to address two problems which had emerged after examination of the KNORR CTD bottle depth data. The problems were:

1. Many productivity casts required 60 liters of water at each of six depths; therefore, two 30-liter bottles on the rosette were fired sequentially at approximately the same depth. It was necessary to edit the bottle depth file for each station so that each depth would be represented by only one pressure and temperature.

2. Certain stations were noticed to have extra or missing record tags compared to the AQUI listings. These stations had to be cross-checked against sampling records and AQUI listings. In the process of checking the listings and recorded depths, it was discovered that the pressure bias corrections for instruments #77 and #48 had been switched during processing for KN95 and KN97. In addition, it was noticed that the pressure biases were quite different during KN98 than during the previous 3 cruises. Thanks to many hours of effort by several program participants, the errors have been identified and corrected. Thanks also to Jane Dunworth for her assistance in correcting and editing the VAX listings.

Copies of the corrected listings were circulated at the Workshop so that KNORR watercatchers can enter correct bottle depths into their respective data sets.

### Nutrients Intercomparison Report
Working Group Coordinator: M. Brown

During the 1983 Alton Jones workshop a working group examined the nutrient data from the R/V KNORR, R/V ENDEAVOR, and R/V OCEANUS to provide an intercomparison among the ships and the analysts. The various nutrient data sets obtained during the 1982 time series cruises consisted of the following:

1. R/V KNORR--Nitrate, nitrite, phosphate, and silicate were analyzed onboard with minimal storage after sampling. The analyses were performed by M. Fox-Brown, P. Bates, and D. Kester. The samples emphasized the upper 100 meters in support of the experimental biology studies and detailed vertical profiles through the water column at a relatively small number of locations relative to the ring.

2. R/V ENDEAVOR--Nitrate, phosphate, and silicate were collected and frozen at sea. The analyses were done ashore by the WHOI nutrient analysis service conducted by Zophia Mlodzinski-Kijowski. Sampling emphasized spatial distributions across the ring with sampling depths throughout the water column.

3. R/V OCEANUS--Nitrate, phosphate, and silicate were collected and frozen at sea. The analysis was performed at WHOI by Zophia for the April cruise and by the TAMU marine technician group for the June and August cruises. Sampling depths were selected to complement the radon and radium sampling, which emphasized the upper few hundred meters and within 100 meters of the sea floor.

Several factors may lead to systematic differences among these data sets, including analytical differences and storage effects. The initial intercomparison was made examining all stations within 20 miles of ring center within a 24-hour interval. These criteria were used in an attempt to avoid spatial and temporal variations. We found that the consistency among the data sets was generally good, but some systematic differences that exceeded expected analytical errors were evident in some of the data sets. The OCEANUS nutrient data during June appeared to be unreliable. There appeared to be a small offset between some of the ENDEAVOR data and that from the KNORR.

A draft was prepared of a detailed nutrient intercomparison report, which examined these data sets quantitatively. In some cases it is difficult to clearly separate analytical inconsistencies among the three data sets from spatial variability associated with the ring. The draft report presents a number of initial conclusions that can be further tested as the remainder of the ENDEAVOR data set becomes available.

## Diatom Report

Working Group Coordinator: T. Smayda

Discussions were held about the different techniques used by different investigators to enumerate diatoms in water samples taken during the warm-core rings cruises and an intercomparison among these techniques is in progress. Priorities were also set for the floristic assessment of the large number of samples collected on the time-series cruises which remain to be worked on.

## Carbon Estimates Report

Working Group Coordinator: Peter H. Wiebe

One aspect of the structure of a marine ecosystem involves assessment of the amount of carbon (as an estimate of biomass) associated with the individual ecosystem components. There have been attempts in the past to summarize the standing crops of carbon in terms of particle size or trophic relationships, but most if not all studies have had to rely on information about some of the ecosystem components from diverse literature sources for measurements made at different times and geographical locations. The suite of measurements made on the multi-ship cruises to warm-core rings provides a unique opportunity to make direct comparisons of the carbon in the various living pools and their relationship to detrital and inorganic particulate matter, and to see what changes in this structure occurred during ring evolution.

During the workshop, a working group was formed to assemble and organize carbon data from specific ring locations where all components had been measured into a form which could be used for these comparisons and to compile a list of methods describing the techniques used to obtain the data. The principal investigators and the components for which they had data are as follows:

| | |
|---|---|
| Ducklow | Bacteria |
| Hitchcock/Langdon/Smayda | Chlorophyll/carbon |
| Smayda/Hitchcock/Langdon | ATP/carbon |
| Nelson/Brzezinski | Diatom/carbon |
| McCarthy | POC+Inorganic carbon/30 L rosette |
| Bishop/Conte | POC/LVFS & MULVFS |
| Cowles | Particle count/carbon |
| Roman/Cowles | Microzoo/carbon (1/4 MOC) |
| Wiebe | Macrozoo/carbon (D1 MOC) |
| Davis/Wiebe | Macrozoo/carbon by taxa |
| Backus/Boyd | Micronekton/carbon (20 MOC) |
| Smith/Yentsch/Boyd | Chlorophyll carbon |
| Blackwelder/Fryxell | Phytoplankton species carbon |

Written descriptions of the techniques used to collect the data and the methods used to derive estimates of carbon for each of the components together with data submitted by the investigators from ring 82-B in April and June 1982 will be circulated as a separate report.

During the 16 July session, C. Davis gave a talk titled "Zooplankton size structure and taxonomic composition from silhouette photographs -- methods and preliminary data."

## MOCNESS Sampling Report
Working Group Coordinator: P. Wiebe

A meeting of investigators whose work involved use of one of the MOCNESS net systems was held to review a recent modification to the method being used to calculate volume of water filtered by a net. Recent mathematical analysis of the geometrical configuration of the MOCNESS during a tow revealed that the algorithm used to calculate volume filtered by a net produced an underestimate when shooting and an overestimate when hauling. The error is dependent upon the vertical velocity of the net frame relative to its horizontal speed. A new algorithm was developed and the magnitude of the errors estimated. These estimates have subsequently been applied to the data for each of the net systems used in the Warm-Core Rings Program.

## Transect Report
Working Group Coordinator: H. Ducklow

The "transect group" consisted of those PI's who participated in cross-ring transects of 82B. The group was formed primarily to examine data collected in the KNORR bottle sampler but was broadened to include others with data on biogenic particulates. These included Bishop, Blackwelder, Smith, and Baker. Our main focus has been on correlating biological and chemical property distributions with physical structures/processes over the ring scale. Our activities at the workshop were directed at resolving our KNORR transect stations into ring coordinates and comparing KNORR contour diagrams of physical properties with the relevant ENDEAVOR plots. After placing our stations in the new revised coordinates we found that:

1). The KNORR transect of days 174-176 crossed within 3km of center.

2). The satellite-determined position of center on day 175 agreed well with the apparent center as judged from property distributions.

3). The KNORR and ENDEAVOR transects show remarkably similar T-S and sigma-t plots even with a 4-6 day time difference and different orientations.

We also explored new ways to analyze the day 168-169 "chord" transect made by KNORR and began to compare Bishop, Blackwelder and KNORR plots.

The principal conclusion of the meetings was that although the ring was distinctly asymmetrical in June, there are close correspondences between physical and biological property distributions. This implies strong control of biogenic property distributions by physical processes at the ring scale. Even though the patterns are asymmetrical, there are distinct patterns characteristic of ring structure in many data sets; i.e., there is a biological ring structure or maybe several such structures. Our future work will focus on distinguishing those properties which correspond to ring physical structure and also on figuring out why some biological distributions are different.

## Chlorophyll Report

Working Group Coordinator: G. Hitchcock

The main objective of the chlorophyll working group during the summer workshop was to describe the chlorophyll distribution within WCR 82B for the period of April-May to June. Initial impressions of several investigators did not agree as to when, or where, the maximum chlorophyll a (CHL A) concentrations occurred. Comparisons of CHL A from Boyd & Wiebe, Smith & Baker, Yentsch & Phinney, and Hitchcock & Smayda from the winter workshop assured us that we can merge the data sets for such an exercise. Comparisons were made of the CHL A and total (CHL A plus phaeopigment) CHL on integrated profiles from 0 to 100 M; future comparisons must be done with BOPS profiles, when the data are available, to 200 M during April-May as the water column showed no structure during that time. Within the ring center (arbitrarily 0 - 30 KMS from center) total CHL was slightly higher in April-May (mean 81.1 MG M-2, range 25-160 MG M-2) than in June (mean 64.9 MG M-2; range 28-137 MG M-2). The wide range of values prevented any statement as to how significant a difference existed between the two months. CHL A showed a similar pattern, decreasing from a mean of 56.0 MG M-2 (range 16-178 MG M-2) in April-May to 43.1 MG M-2 (range 7-89 MG M-2) in June. For the area outside the ring center (arbitrarily 30-80 KMS from ring center) total CHL ranged from 120-200 MG M-2, coincident with the spring bloom in the Slope Waters. In June the "outer ring" values ranged from 30 to 108 MG M-2 indicating that there was little difference in total CHL biomass upper 100 M from April to June, although the concentrations within the ring were generally less than those in contiguous Slope Waters in April-May, and equivalent to those in Slope Waters in June. A complete data report, including graphs and tabulated data, is available from G. Hitchcock.

## 81-D Report

Working Group Coordinator: J. McCarthy

For many who are working up data from the A-II cruise in WCR 81-D there is considerable uncertainty as to whether "ring center" data sets for 9/23 (day 266), 9/26 (day 269), and 10/2 (day 275) can be used to infer temporal changes in ring center. The extreme alternative is that they merely indicate that the mixed layer properties near ring center were spatially variable during this period.

A meeting was convened to determine the level of interest in this problem, and to explore lines of investigation that might provide an explanation(s) for the differences observed in the ring center mixed layer during the A-II cruise.

Joyce et al's paper on "rapid evolution" documents the gross physical changes that occurred in 81-D during the day 266-275 period. With reference to the ring center issue, it is apparent that the salinity in this region decreased from about 36 to about 35.5 and then increased again to about 36. The minimum values are shown for day 267, and although his figure includes data from the A-II, logs for the A-II CTD and MOC data indicate that 35.5 was observed several times on day 269. The figure for surface salinity measurements made during the 3 day XBT star following the Gulf Stream interaction shows values of both 35.5 and 36 very near the ring center position.

Between days 269 and 275 the storm we all remember is well documented. At ring center the depth of the mixed layer doubled, surface temperatures declined, and nitrate increased to measurable concentrations throughout the mixed layer. On the other hand, in the three days prior to this period (day 266-269), silicate appears to have gone from undetectable to about 1 $\mu$ mol/kg and then changed little if at all between days 269 and 275. Lateral entrainment could have introduced silicate to the ring center region, but the vertical mixing necessary to increase silicate in the manner observed would have resulted in nitrate increases greatly in excess of those observed.

Much of the preliminary data on abundance and species composition of the organisms indicate that biomass was higher on day 275 than on day 269, and that there were no dramatic shifts in species composition for either the phytoplankton or zooplankton. As indicated in the Joyce et al paper, Backus's neuston data show substantial differences between the day 263-275 observations when salinity decreased, and Backus suggests that faunal analyses support the argument of Gulf Stream water entering the ring center region.

Schmitt reminded us of his earlier efforts to explain the changes in salinity and temperature between days 269 and 275 with a mixed layer model that considered the effects of vertical entrainment and air sea interactions. Given the available data, the degree of vertical mixing necessary to increase surface salts from 35.5 to 36 would be insufficient to account for the observed temperature change. This finding leads to the conclusion that lateral entrainment was responsible for the spatial, and apparent temporal, variability observed near ring center during the ENDEAVOR and A-II cruises.

To be more confident of this position, the following was decided:

1) Schmitt offered to re-examine his model results,

2) Someone should compare the "end" surface data (used in Joyce's plots) and the A-II station data during the same period of time, in order to address ambiguity that now exists between "end" and A-II observations for surface S and T, and,

3) A detailed event log or chronology needs to be worked out for 81-D, analogous to that which Karen Baker has presented for 82-B.

<u>15 July addendum:</u> Schmitt did re-examine the results of his model, and concludes that the differences in mixed layer temperature and salinity between days 269 and 275 cannot be explained on the basis of vertical entrainment. He concludes that these differences should be attributed to spatial variability, with the low salinity features arising from streamers formed in the peripheral region that were swept inward towards ring center.

## <u>Entrainment Report</u>
Working Group Coordinator: T. Joyce

Three principal investigators (T. Joyce, J. Bishop, and P. Wiebe) and a graduate student (M. Conte) constituted this informal working group. While initially focussing on using common scales to plot data from the second multi-ship experiment in the entrainment region in June, we expanded the exercise to include the first multi-ship experiment in ring center as well. It was apparent from the acoustic doppler, CTD-transmissometer, and MOCNESS data that a high degree of correlation was present in the different data sets on small spatial scales. We were surprised to see the similarity between transmissometer light scattering and patterns of 300 khz acoustic scattering levels in the entrainment zone. During the workshop, an oral presentation was given on the June multiship data, and the participants are planning a joint manuscript.

## Ring Chronology Report

Working Group Coordinators: K. Baker/R. Evans

The Ring Event Working Group was concerned with identifying and categorizing the major physical events in the hydrographic and satellite derived histories of warm-core ring 82-B. The first problem the group addressed was determining which events should be followed over time. The major events considered were:

1) Meteorological events (percent cloud cover and wind)
2) Topographic interactions
3) Streamer events (warm and cold)
4) Entrainment events (warm and cold)
5) Large scale current interactions (ring-ring and ring-Gulf Stream)
6) Small scale events (patchiness)
7) Formation/Death events.

During the choosing of these events, it became evident that the description, indeed the very identification, of the events was being hampered by an uncommon vocabulary -- an entrainment to one was a streamer to another. Considerable effort was spent on determining how best to define each event and what each really encompassed. One of the products of the working group, then, was a ring glossary which will appear in a future newsletter.

The group then integrated the satellite and in situ observations to produce a chronology of these various events. Also included in the time line were the extent of the satellite (AVHRR and CZCS), ship, and drifter coverage. This allowed for a rapid decision with regard to which data sets were available for a particular analysis during a particular time. These results and a portion of the glossary were presented by Karen Baker during one of the workshop seminars.

## Modelling Report

Working Group Coordinator: G. Flierl

The modelling group discussed the state of modelling of various physical and biological processes and suggested new areas of research based upon the data presentations and synthesis.

Thursday 7/14. The first discussions on one of our major topics-- the dynamics of the streamers-- began with an attempt to apply balance equation models to the motion of a small annulus of anomalous water introduced into the ring and calculations of the spin-down of a ring. The following streamer problem was proposed: if a ring of fluid with different density but possibly the same velocity as the surrounding water is introduced at some radius, will it move inward under the influence of unbalanced pressure forces? A quick estimate suggested that the streamer would only move a few km and develop anomalies of velocity on the order of 200 cm/sec, but further work seemed necessary. Is it possible to find a case in which the streamer really is self-propelled into the center?

A balance model for the spin-down was proposed which suggested that the vertically integrated radial velocity was outward; furthermore, based on the rate of rise of the thermocline, these outward flows would be only of .01 cm/sec. The displacements associated with the spin-down are tiny. Can this be done for the stratified case without depth-averaging?

Friday 7/15. The subject here was the effect of internal waves upon phytoplankton growth. Using a logistic equation with depth-variable growth rates and vertical motions due to internal waves, one finds that the average growth rates following the plankton are increased due to the curvature in the light vs. depth profiles. In the Lagrangian (particle following) sense, this leads to both increased growth rates and increased sustainable biomass. If one wishes to make an Eulerian (fixed depth) spatial average, one finds somewhat different results since one is averaging over plants in different parts of the wave-induced cycles. For high frequency waves, the sustainable population is larger than in the absence of waves-- in fact even larger than one would guess from the Lagrangian model. How does phyto growth depend on frequency of light fluctuations? How do conclusions change if one includes photoinhibition? What kind of model should one study -- a model of exponentially growing phytoplankton affected by internal waves, a model incorporating some kind of self limitation, or a multi-component model (phytoplankton, nutrients, etc.) -- to best understand the importance of these vertical motions? Will such a model be relevant for the observations of silica utilization very deep in the water column?

Saturday 7/16. Attempted to use Nof and Flierl's models to calculate the theoretically predicted westward and southward drifts of the rings. Calculations of net ring volume and azimuthal transport seemed to give speeds substantially smaller than previous calculations. (Olson and Flierl have straightened this out-- models predict c=(-1,-2) cm/sec roughly-- the southward speed is not well predicted since it is outside the bounds of validity of the model).

Chris Evans described analyses of the rings formed in Holland's GCM calculations. The model rings seem to be imbedded in and energetically connected to a larger scale more barotropic flow field. Chris plans to work on the energetics.

Sunday 7/17. Further discussions on streamers. Generally it was felt that the axisymmetric adjustment model would not be terribly successful. Some argument ensued concerning the possibilities of modelling the streamer as a blob started with a sizeable inward velocity, evolving under the influence of the ring's pressure field; this is still unresolved. A similar question was raised as to whether non-axisymmetric motions, properly tuned with the ring's rotation could advect passive tracers into the center without requiring overall divergence or dynamically anomalous features.

Solution for the internal structure of the frictionally decaying single layer model was described. There is outflow along the interface and inflow in the interior with the net transport still being outward. The inward flows are far too weak to account for streamer motion.

Monday 7/18. Summary session with Allan Robinson, describing the various ongoing research efforts:

1) Structure and Motion. Nof and Flierl are working on the flows in the deep layer and their influence on the ring. Current work has assumed that the ratio of the upper layer depth to the lower layer depth is small compared to the ratio of $\beta L^2$ whereas the opposite is the case. Ikeda and Evans are analyzing the structures found in numerical models with particular interest in the companion or associated structures. The latter may relate to the "modons".

2) Streamers. Mied showed some numerical work with streamers developing during the interaction of two eddies (but not penetrating all the way in). These were basically a response to the time-dependent parts of the flows; there were strong suggestions that the appearance of the structures depended critically upon the value for the viscosity and diffusivity.

3) Mixed layer dynamics. Dewar, Joyce, and Flierl are very interested in the evolution of mixed layers in rings, particularly in the wintertime. The questions of how the deep convection may alter the ring structure and the use of this as a prototype for bottom water or 18°C water seem intriguing.

4) Interactions with topography and the Gulf Stream, the relationship between the ring structure and that of the Stream, understanding of the role of dissipation in ring decay, etc. Other topics such as these were discussed briefly but will need more detailed consideration in the future.

Group generally consisted of Dewar, Evans, Flierl, Franks, Ikeda, Joyce, Mied, Nof, Olson, Schlitz, Schmitt, Wroblewski.

## IV. NASA Ocean Color Report

Report by: J. McCarthy

On July 8, 1983, the NASA Color Group met during the WCR workshop at Alton Jones. The purpose of the meeting was to refine plans regarding algorithm development for the proposed Ocean Color Imager. In that this group includes O. Brown, R. Smith, R. Evans, and J. McCarthy in addition to other scientists, plus representatives from both NASA and NOAA, it was decided to convene at Alton Jones in order to minimize disruption of the WCR workshop.

Problems related to the algorithm development for Case I and Case II waters were discussed, and plans were laid for pre- and post-flight studies that will permit accurate estimation of the aerosol correction factors, and regular assessment of sensor performance. Rough budgets were developed for the shipboard work that will be necessary to support these studies.

One question that remains pertains to the need for an aircraft simulation of the OCI type sensor prior to launch.

V. Some WCR Publications Submitted, In Press or Published Recently

C -- Submitted
D -- In press
E -- Published

| NAME | TITLE OF PAPER/ABSTRACT | JOURNAL | STATUS |
|---|---|---|---|
| J. Bishop, D. Schupack, R. Sherrell, M. Conte | A Multiple Unit Large Volume In-Situ Filtration System for Sampling Oceanic Particulate Matter in Mesoscale Environments | ACS Symp. | C |
| O. Brown, D. Olson, J. Brown & R. Evans | Kinematics of a Gulf Stream Warm Core Ring | Aust. J. Mar Freshwater Res. | D |
| G. Flierl | The Impact of WCR's Upon the Slope Water | Hawaii Winter Wrkshp Conf. Proceed | D |
| G. Flierl, M. Stern & J. Whitehead | The Physical Significance of Modons: Laboratory Experiments and General Integral Constraints | Dyn At Oc | D |
| G. Flierl | Rossby Wave Radiation from a Moving Nonlinear Ring | JPO | D |
| G. Flierl | A Simple Model for the Structure and Motion of a WCR | Aust. J. Mar. Freshwater Res. | D |
| G. Flierl & J. Wroblewski | The Possible Influence of WCR's on Larval Fish Distributions Off the NE United States | Fish. Bull | C |
| G. Fryxell, R. Gould & T. Watkins | Gelatinous Colonies of Thalassiosira in Gulf Stream Warm Core Rings | Brit. J. of Phycol. | C |
| T.Joyce, R.Backus K.Baker, P. Blackwelder, O. Brown, R.Evans, G.Fryxell D.Mountain, D. Olson, R. Schlitz, R.Schmitt, P. Smith, R. Smith & P. Wiebe | Rapid Evolution of a Gulf Stream WCR | Nature | C |
| T.Joyce, R. Schmitt & M. Stalcup | Influence of the Gulf Stream upon the short term evolution of a warm-core ring | Aust. J. Mar. Freshwater Res. | D |

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| T.Joyce & M. Stalcup | An Upper Ocean Current Jet and Internal Waves in a Gulf Stream Warm Core Ring | JGR | C |
| T. Joyce & P. Wiebe | Warm Core Rings of the Gulf Stream | Oceanus | E |
| C. Langdon | Dissolved Oxygen Monitoring System Using a Pulsed Electrode. Design, Performance & Evaluation | D.S.R. | C |
| WCR Exec. Comm. | Multidisciplinary Program to Study Warm Core Rings | EOS | E |
| J. Wroblewski & J. Cheney | Ichthyoplankton Associated with a WCR Off the Scotian Shelf | Can. J. Fish & Aqu. Sci. | D |
| P. Glibert & J. McCarthy | Uptake and Assimilation of Ammonium and Nitrate by Phytoplankton: Indices of Nutritional Status for Natural Assemblages | J. Plank. Res. | C |